Artist rendition of human exobiologist and geologist on Mars.
Credit: NASA / Pat Rawlings

Astrobiology Technology Branch (SSR) Overview

The Astrobiology Technology Branch supports fundamental research and the development of advanced technologies in astrobiology as they relate to the exploration of space and understanding life in the universe. Current branch efforts encompass research and technology development for advanced life support, utilization of planetary resources, and astrobiology. Advanced Life Support focused research is directed primarily at physicochemical processes for use in regenerative life support systems required for future human missions and includes atmosphere revitalization, water recovery, waste processing / resource recovery, and systems modeling, analysis and controls associated with integrated subsystems operation. In-Situ Resource Utilization (ISRU) technologies will become increasingly important on every Mars lander between 2003 and a human mission to Mars. The branch focus is on the development of technologies for Mars atmosphere acquisition, buffer gas production, and CO_2 compression. Research and technology development for astrobiology includes understanding the physical and chemical limits to which life has adapted on Earth, the molecular adaptations that have allowed living systems to inhabit extreme environments, and the application of this knowledge to biotechnology, nanotechnology, and planetary protection. Researchers in the branch also develop flight experiments and associated hardware for shuttle, ISS, and unmanned NASA missions.

Mark H. Kliss

Chief, Astrobiology Technology Branch (SSR)

ATMOSPHERIC RESOURCES FOR EXPLORATION OF MARS

John Finn, Dave Affleck, and Lila Mulloth

The atmosphere of Mars has many of the ingredients needed to support human exploration missions. It can be "mined" and processed to produce oxygen and buffer gas for breathing (used to dilute oxygen). With lightweight hydrogen transported from Earth, or using water found in local deposits as a hydrogen source, storable methane rocket fuel can also be produced. The use of local materials, called ISRU (for *in situ* resource utilization), is an essential strategy for a long-term human presence on Mars from the standpoints of self-sufficiency, safety, and cost. It is a key cost-reduction element of NASA's Strategic Plan.

The atmosphere of Mars is roughly 95% carbon dioxide, 3% nitrogen, and 2% argon. There are also trace amounts of other gases. Carbon dioxide is the resource for oxygen and also provides the carbon that can be used in methane production. The production of these gases will likely dominate any early Mars manufacturing plant because of the quantity of materials needed to return samples or humans to orbit or to Earth. However, it is important to recognize that buffer gas also represents a considerable launch mass, estimated on the order of two to three tons for a human mission (mainly due to airlock activity). With the proper selection of gas acquisition and processing technology, a more optimal ISRU plant can be designed that will provide all these resources with minimal mass and power consumption.

For example, carbon dioxide must be acquired from the Mars atmosphere, purified, and pressurized in order to be useful in a propellant production plant. Buffer gas is a potential by-product of the purification process. NASA Ames developed a process whereby the small amount of nitrogen and argon present in the atmosphere are efficiently separated from the carbon dioxide during an adsorption compression process (see Figure 5). Carbon dioxide adsorbs in the first bed, while nitrogen and argon pass through and are collected in a separate adsorption bed. When the first bed is heated, carbon dioxide is driven off at elevated pressure. Similarly, the nitrogen and argon are driven off at pressure when the second bed is heated. Such temperature-swing adsorption compression and separation processes are highly efficient and are expected to work well on the cold Martian surface. Being virtually solid-state, they do not suffer the wear and reliability problems associated with operating mechanical pumps in that hostile environment. ❑

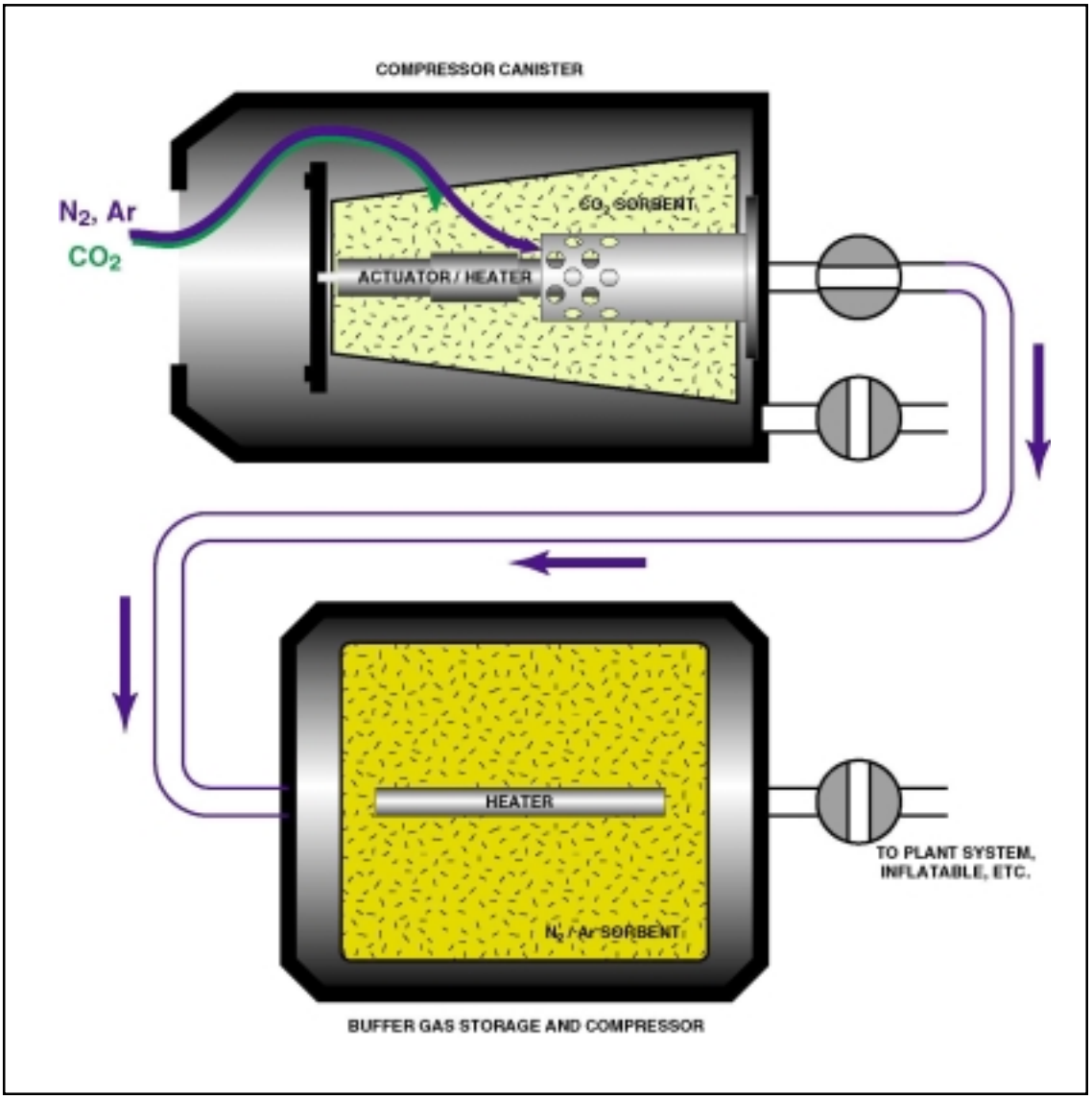

Figure 5: Flow diagram of an adsorption-based CO_2 compression and N_2-Ar separation device for the Mars atmosphere.

CLEAN INCINERATION FOR SPACE MISSIONS

John W. Fisher and Suresh Pisharody

One of the research objectives at NASA Ames Research Center is the development of solid waste processing technologies for long duration exploration missions. A major part of this research effort entails the recovery of resources from life support wastes, such as the recovery of carbon dioxide and water from waste biomass via incineration. Carbon dioxide and water can be used as part of a regenerative life support system to grow plants for food. One of the central problems associated with incineration is the production of undesirable or toxic byproducts of combustion. Ames has developed an incineration flue gas cleanup system that allows use of the carbon dioxide in a plant growth system and that allows release of the remainder of the clean flue gas back to the crew cabin.

As space missions increase in duration, there will be an increased need to transition from life support systems using stored life support materials to life support systems using recycled life support materials. For instance, for short duration missions food can be stored, however, for missions lasting several years, food will need to be provided from a number of possible sources. One viable source is a plant growth chamber. Growing food in space will require recycling waste materials for the raw materials necessary for plant growth: carbon dioxide, water, and nutrients. Incineration offers a method of converting waste materials such as inedible biomass (the part of a plant that can not be eaten) back into carbon dioxide, water, and nutrients (ash).

The process of combustion of biomass in an incinerator operates in a way similar to the combustion of wood in a fireplace – the biomass is almost completely oxidized to gaseous carbon dioxide and water vapor, and only a small residue of inorganic substances (ash) is left. Even in the best of combustors, however, some unoxidized material remains, and toxic byproducts and/or contaminants such as nitrogen and sulfur oxides are formed.

In recent years, research at Ames has focused on developing methods to eliminate the undesirable combustion byproducts. One approach has been to use reductive catalytic systems to convert the nitrogen and sulfur oxides to nitrogen and elemental sulfur, innocuous materials at room temperature. Oxidative catalysts can then oxidize the remaining hydrocarbon contaminants to very low levels. In collaboration with outside university and corporate organizations, an integrated incineration system has been developed and tested that utilizes a fluidized-bed combustor followed by a catalytic cleanup system. In the past year, this system has demonstrated the ability to burn inedible biomass and produce a very clean exit flue gas. The concentration of contaminants in the gas exiting the incinerator is generally less than a few parts per million. Except for the carbon dioxide, which is toxic to humans at high concentrations, the exit stream from the incinerator is able to meet the Space Maximum Allowable Contaminant (SMAC) standards for clean air in a spacecraft.

A second research effort at Ames is investigating the use of waste material to prepare the flue gas cleanup system. A pyrolytic process converts inedible biomass to char, and the char is then converted to activated carbon. The activated carbon is used to remove contaminants such as nitrogen oxide and sulfur dioxide from the incinerator flue gas by adsorption followed by chemical reaction with the carbon. The contaminants are thus converted to innocuous nitrogen gas and elemental sulfur. In the past year, the process of producing activated carbon from wheat straw has been demonstrated, and the activated carbon produced from wheat straw has been used to reduce the concentration of nitrogen oxides in incinerator flue gas from 300 ppm (parts per million) to less than 1 ppm. This meets the SMAC limits within the crew cabin.

With the development of energy efficient, optimized incineration and flue gas cleanup systems, NASA will have the technology necessary to "close the loop" on carbon. Ultimately, carbon will move within the system from plant to person and / or incinerator and back to the plant without ever becoming a stored waste, achieving a significant milestone in the development of advanced life support systems which approach self-sufficiency. ❑

ROTATING-DISK ANALYTICAL SYSTEM (R-DAS)

Michael Flynn and Bruce Borchers

One of the main limitations in increasing the scientific return from fundamental biology and life sciences experiments onboard the International Space Station (ISS) is the inability to conduct a variety of biological and analytical assays in flight. The Rotating-Disk Analytical System (R-DAS) is an automated analytical / cell culture laboratory that has been developed as a biotech and chemical analytical instrument for use on ISS and other space flight platforms. R-DAS uses a microfluidics rotating disk and predetermined spinning profiles to accomplish complex fluid management tasks. Analysis is accomplished through the use of a custom optical imaging system. The instrument can conduct a wide range of protocols on orbit with onboard 1-g and micro-g controls without the need for the ISS centrifuge.

The system has a variety of unique design features such as automated microgravity environment assays and optical detection schemes which support natural and induced fluorescence. It is capable of conducting calorimetric, spectral, and image analysis. It will provide in-flight 1-g control studies without the need for the ISS centrifuge. It uses sealed and disposable sample disks which are pre-configured with all necessary reagents. The use of centrifugal force to control fluid flow minimizes acceleration velocities and shear forces and creates an environment which is insensitive to two-phase microgravity flow restrictions thereby simplifying sample preparation and introduction procedures.

The system is designed to fit into a double mid-deck locker (1 / 4 Space Station rack). It is designed to remain on orbit with only the disks being transported back and forth to orbit. A disk storage / holding

system will be provided in order to allow for multiple disks processing. Operational protocols can be written on CD disks and experimental results can be re-written on the CD disks.

Ames Research Center has recently completed a rapid system prototype development effort. This six-month effort has resulted in the development of the prototype R-DAS system. The prototype is shown in Figure 6. This system is fully automated and uses a single microfluidic disk (single assay) with six parallel flow paths. The disk is shown in Figure 7. A florescent microscope is incorporated into the design in order to image samples and provide complete image analysis. The system is portable, having dimensions of only 8 in. x 20 in. x 20 in. The prototype was completed on January 1, 2002, and is currently being validated against standard laboratory protocols. In order to provide a first demonstration assay, a unique microfluidic disk was fabricated using the Molecular Probes Live / Dead stain assay.

Live / Dead Bacterial Viability Kit stains are based on the use of SYTO 9 green fluorescent nucleic acid stain and the propidium iodide red-fluorescent stain. Live / Dead kits are also available for animal cells and yeast assays, both of which will work in the existing R-DAS disk system.

Initial test results from the prototype system Live / Dead assay are encouraging. In addition, the system design is such that R-DAS is readily adaptable to a variety of other assays / disks being evaluated. With further development, R-DAS promises to usher in previously unavailable biological laboratory analysis capability onboard ISS and other future space flight platforms. ❑

Figure 6: R-DAS Instrument

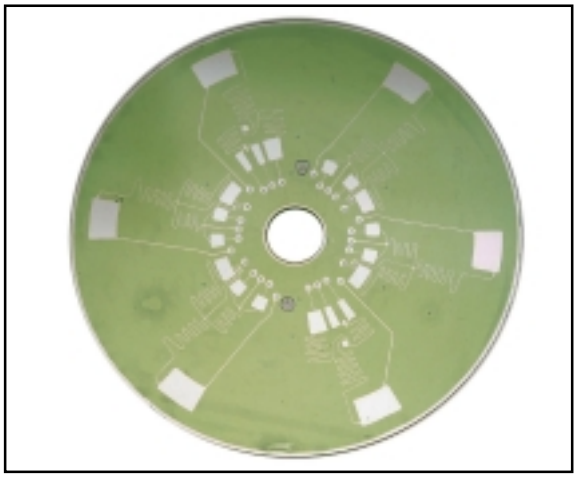

Figure 7: R-DAS Microfluidic Disk.

PROTEIN NANOTECHNOLOGY

Jonathan Trent, Andrew McMillan, and Chad Paavola

In support of NASA's efforts to improve mission success, there is a growing need for the development of smaller, stronger and 'smarter' scientific probes compatible with space exploration. The necessary breakthroughs in this area may well be achieved in the revolutionary field of nanotechnology. This is technology on the scale of molecules, which holds the promise of creating devices smaller and more efficient than anything currently available. Although a great deal of exciting research is developing around carbon nanotubes-based nanotechnology, investigators at NASA Ames Research Center are also exploring biologically inspired nanotechnology.

The biological 'unit', the living cell, may be considered the ultimate nano-scale device. Cells, which are constructed of nano-scale components, are extremely sensitive, highly efficient environmental sensors capable of rapid self-assembly, flawless self-repair, and adaptive self-improvement; not to mention their potential for nearly unlimited self-replicate. Ames is focusing on a major component of all cells (proteins) that are capable of self-assembling into highly ordered structures. A protein known as HSP60 is currently being studied that spontaneously forms nano-scale ring structures (Figure 8A, end view; B, side view), which can be induced to form chains (Figure 8C) or filaments (Figure 8D).

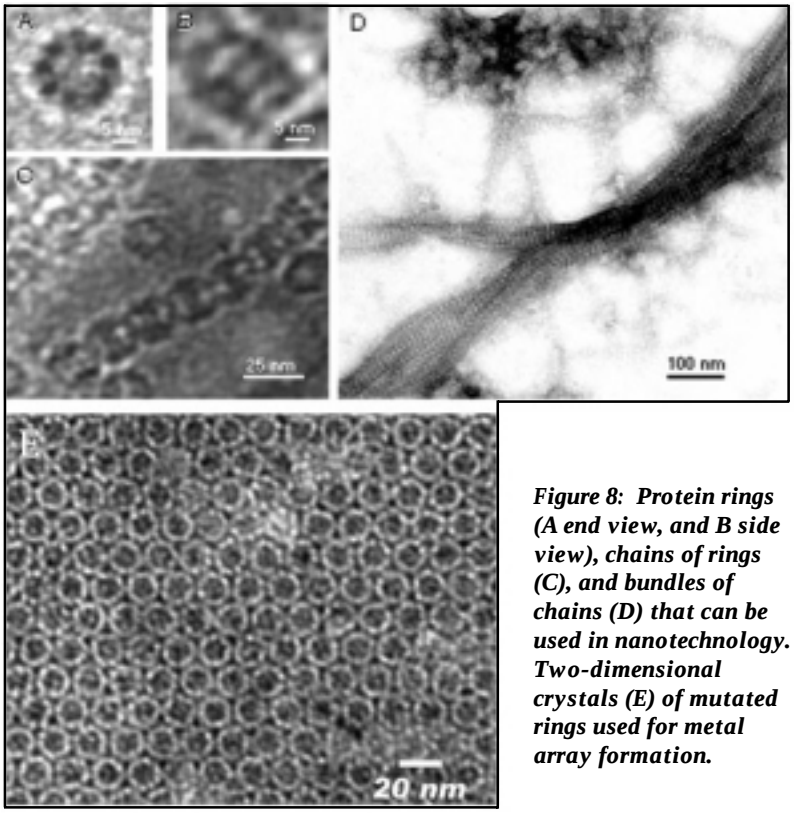

Figure 8: Protein rings (A end view, and B side view), chains of rings (C), and bundles of chains (D) that can be used in nanotechnology. Two-dimensional crystals (E) of mutated rings used for metal array formation.

By using thermostable HSP60s, highly efficient methods have been developed for purifying large quantities of these proteins and by using the 'tools' of molecular biology, their composition and structure-forming capabilities are being currently modified.

Recently, progress has been made in evolving the HSP60 into a structural subunit that can be manipulated in such a way as to utilize it for the formation of ordered arrays. Ordered arrays of metals are of interest in the semiconductor engineering community for the fabrication of devices that can be addressed and further assembled into logical circuits. To this end, a portion of the wild-type HSP60 subunit identified as contributing to the formation of filaments, or end-on structures, has been removed at the genetic level. The removal of this region of DNA directs the expression of a protein incapable of organizing into filaments; however, it possesses the ability to crystallize in two dimensions in a highly ordered hexagonally packed array (Figure 8E). This ordered array is being used to direct deposition of metals by templating. This process takes advantage of both the propensity of the modified subunit to self-assemble into a highly ordered array and the ability to site-specifically functionalize the protein. Using this approach, specificity for metals can be engineered into the protein that will subsequently localize the metals at defined intervals along the protein and hence into an ordered array (Figure 9). A simple removal of the protein leaves the ordered array of metal on the substrate with nanometer scale feature resolution. ❑

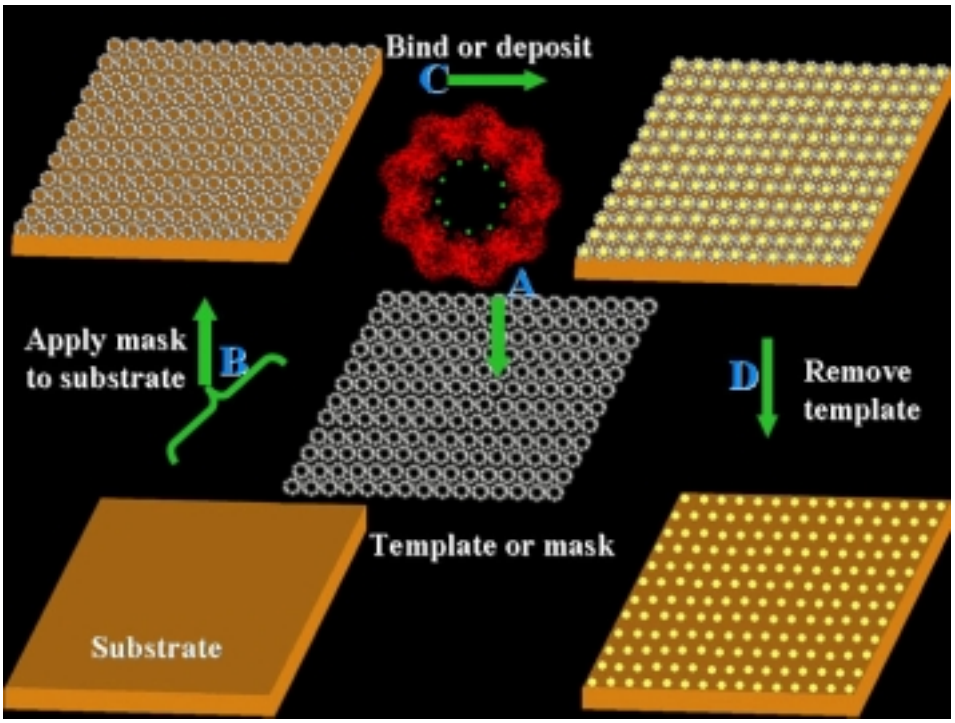

Figure 9: Mutant forms of HSP60 possess genetically engineered chemical reactivity at specific sites on the rings (A, green dots). These rings are crystallized (A) in two dimensions forming a highly ordered template. The template is applied to the surface of a substrate (B), and metals are bound that specifically attach to defined sites throughout the crystal (C). Finally, the template is removed (D), and the ordered array remains bound to the substrate.